MACHINING ALCOA ALUMINUM

ALUMINUM COMPANY OF AMERICA

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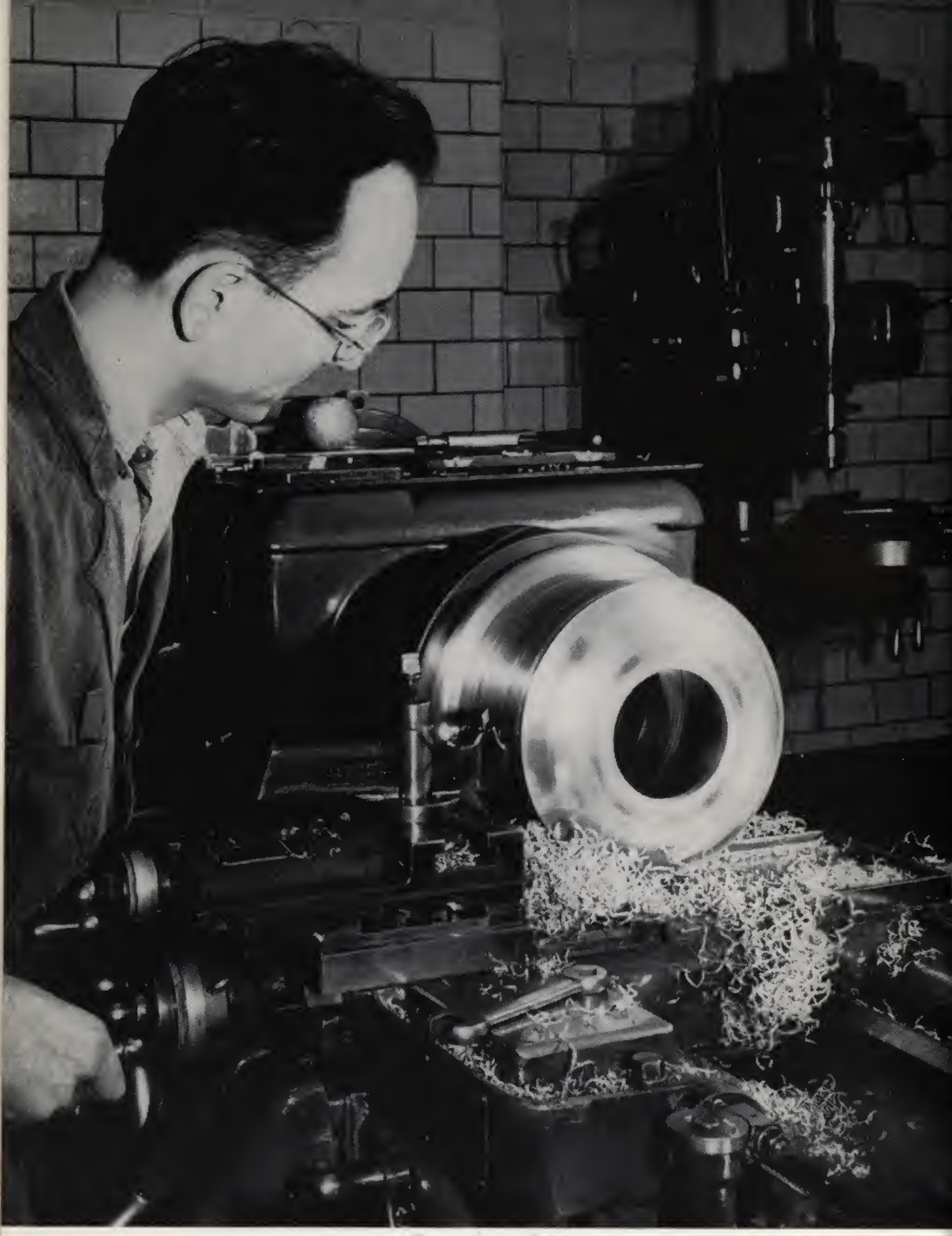
PITTSBURGH, PA.



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INTRODUCTION

An important consideration in the selection of a metal for many applications is the ease with which the metal can be fashioned into the finished article by machining. Alcoa aluminum offers many advantages, for it *does* possess good machining characteristics. This booklet presents information for use by tool designers and machinists so that these advantages may be more fully realized.

Tools and practices commonly employed in machining steel often perform satisfactorily when applied to some of the aluminum alloys. However, because of the relatively wide range of chemical, metallurgical and physical characteristics exhibited by the complete family of aluminum alloys, it is necessary to employ somewhat different machining procedures to attain optimum performance.

It is, therefore, the purpose of this booklet:

1. To outline specific, desirable characteristics in tools for machining aluminum and its alloys.
2. To suggest speeds, feeds and depths of cuts which will operate these tools satisfactorily.
3. To indicate where common practice as well as tools of standard design may be used.
4. To point out where the use of special practices or tools will produce better results.

TEMPER DESIGNATIONS OF ALUMINUM ALLOYS

—F As fabricated.

—O Annealed, recrystallized (wrought products only).

—H Strain-hardened.

- —H1, plus one or more digits. Strain-hardened only.
- —H2, plus one or more digits. Strain-hardened and then partial annealed.
- —H3, plus one or more digits. Strain-hardened and then stabilized.

—W Solution heat-treated—unstable temper.

—T Treated to produce stable tempers other than —F, —O, or —H.

- —T2 Annealed (cast products only).
- —T3 Solution heat-treated and then cold-worked.
- —T4 Solution heat-treated.
- —T5 Artificially aged only.
- —T6 Solution heat-treated and then artificially aged.
- —T7 Solution heat-treated and then stabilized.
- —T8 Solution heat-treated, cold-worked, and then artificially aged.
- —T9 Solution heat-treated, artificially aged, and then cold-worked.
- —T10 Artificially aged and then cold-worked.

CHARACTERISTICS OF ALUMINUM ALLOYS

The word "aluminum" is commonly used to describe the pure metal and its alloys in various tempers of cast or wrought products. Each alloy is identified by a number which is followed by the letter "S" only if the alloy represents a wrought product. Tempers are designated in accordance with the symbols shown on the facing page.

The nominal chemical compositions of some of the aluminum alloys are presented in Table 1, page 8. Typical mechanical properties of these alloys may be found in Tables 4, 5 and 6, pages 58, 60 and 62, respectively.

Aluminum weighs only about one-third as much as steel or brass; hence, its use is frequently more economical because more pieces of a given size can be made from the same total weight of metal and each part can be handled with greater ease. Its lighter weight also permits higher machining speeds when inertia forces are controlling factors.

Aluminum "springs" about three times as much as steel under a given load and, although this characteristic is used frequently to advantage in the application of the part to be machined, it offers a disadvantage in some machining operations. Care should be exercised in clamping or chucking aluminum to insure that the work is not distorted.

Aluminum expands or contracts about twice as much as steel for a given change in temperature. A good general rule to remember is that each inch of aluminum expands or

TABLE I—Nominal Composition and Relative Machinability of Commercial Aluminum Alloys

Type[1]	Alloy	Per Cent of Alloying Elements—Aluminum and Normal Impurities Constitute Remainder					
		Copper	Silicon	Magnesium	Manganese	Zinc	Others
				NONHEAT-TREATABLE CASTING ALLOYS			
I	C113	7.0	3.5	...	...	...	...
II	113	7.0	2.0	...	...	1.7	...
	138	10.0	4.0	0.3	...	...	...
	A214	...	...	3.8	...	1.8	...
	214	...	...	3.8	...	...	...
	212	8.0	1.2	...	...	...	...
	F214	...	0.5	3.8	...	...	...
	B214	...	1.8	3.8	...	...	...
	A612	0.5	...	0.7	...	6.5	...
	C612	0.5	...	0.35	...	6.5	...
III	A108	4.5	5.5	...	...	...	...
	108	4.0	3.0	...	...	...	...
	319	3.5	6.3	...	...	...	...
	43	...	5.0	...	...	...	...
				HEAT-TREATABLE CASTING ALLOYS[2]			
I	750	1.0	...	...	...	...	1.0 Nickel + 6.5 Tin
	220	...	...	10.0	...	...	...
	122	10.0	...	0.2	...	...	...
II	142	4.0	...	1.5	...	...	2.0 Nickel
	195	4.5	0.8	...	...	...	...
	B195	4.5	2.5	...	...	...	...
III	355	1.3	5.0	0.5	...	...	...
	319	3.5	6.3	...	...	...	...
	356	...	7.0	0.3	...	...	...
	333	3.8	9.0	...	...	...	...
	D132[3]	3.5	9.0	0.8	...	...	0.8 Nickel
	A132[3]	0.8	12.0	1.2	...	...	2.5 Nickel

HEAT-TREATABLE WROUGHT ALLOYS[2]

I	11S	5.5	...	...	...	...	0.5 Lead + 0.5 Bismuth
II	17S	4.0	...	0.5	0.5	...	...
	A17S	2.5	...	...	0.3	...	...
	24S	4.5	...	1.5	0.6	...	...
	14S	4.4	0.8	0.4	0.8	...	...
	75S	1.6	...	2.5	0.2	5.6	0.3 Chromium
	25S	4.5	0.8	...	0.8	...	...
	B18S	4.0	...	1.5	...	...	2.0 Nickel
	18S	4.0	...	0.6	...	...	2.0 Nickel
III	61S	0.25	0.6	1.0	...	...	0.25 Chromium
	62S	0.25	0.6	1.0	...	...	...
	53S	...	0.7	1.3	...	...	0.25 Chromium
	63S	...	0.4	0.7	...	...	...
	A51S	...	1.0	0.6	...	...	0.25 Chromium
	32S[3]	0.9	12.2	1.1	...	...	0.9 Nickel

NONHEAT-TREATABLE WROUGHT ALLOYS[2]

II	56S	...	...	5.2	0.1	...	0.1 Chromium
III	52S	...	...	2.5	...	...	0.25 Chromium
	B50S	...	...	1.2	...	...	...
	4S	...	...	1.0	1.2	...	...
	3S	...	...	...	1.2	...	...
	2S[4]	...	...	...	...	...	...
	BD1S	...	...	...	...	...	...
	EC[5]	...	...	...	...	...	...

[1] Indicates relative machinability. Type III—Good; Type II—Better; Type I—Best.

[2] Machinability ratings based on heat-treated or strain-hardened products. All alloys in annealed temper are in Type III.

[3] Alloy cuts freely, but tools may wear excessively if not tipped with cemented carbides.

[4] 99 per cent minimum aluminum.

[5] Electrical conductor grade. 99.45 per cent minimum aluminum.

contracts approximately 0.0001 inch when the temperature changes 8° F. Dimensional accuracy in the finished work can be maintained only by minimizing heat in the work and by completing finishing cuts at normal temperatures. Overheating of the work may arise from the use of improperly designed or dull tools, from failure to use a lubricant when required, or from the use of heavy feeds or cuts. Changes in dimensions are sometimes encountered in aluminum alloy products during machining operations. Such distortion may result from redistribution or relief of the residual stresses induced by heat treatment. The magnitude of the residual stress produced by solution heat treatment depends upon the composition of the alloy, heat treating temperature, temperature and nature of the quenching media, and upon the size and shape of the part. The amount of distortion, where encountered during machining, is influenced by the design and size of the part and by the character and sequence of the machining operations. By balancing machining operations so as to avoid machining to finished dimensions from one side only, these distortion effects can be minimized. Employing an extra light finishing cut will also aid in correcting dimensional changes and distortion resulting from relief of residual stresses in the part.

An outstanding characteristic of aluminum alloys is the ease with which they can be machined. The principal factors which affect the relative machinabilities are chemical composition, physical form (cast or wrought) and temper. In Table 1, commercial aluminum alloys are segregated into groups, depending upon whether they are cast or wrought, heat-treatable or nonheat-treatable. Within each group the alloys are arranged in the approximate order of their relative machinability when each alloy is considered to be in its most machinable condition. The machinability characteristics of

Louisiana

Mississippi Texas

Type III alloys are good; those of Type II are better; and those of Type I are best.

Machinability is a broad term which includes considerations such as ease of cutting, chip characteristics, quality of finish and tool life. Many of the aluminum alloys can be cut fast; the chips are small; smooth surfaces can be produced readily; and tool life is long. Other alloys are more difficult to machine; they produce cuttings that are long and stringy—while still others are soft and gummy. Those alloys containing relatively large amounts of silicon are abrasive to carbon and high-speed steel tools, but can be machined satisfactorily with cemented carbide tools. It is frequently impossible to attain optimum performance in all of the factors which comprise machinability. Thus, tools with rake angles designed for maximum ease of cutting and surface quality might produce cuttings having undesirable characteristics. Limitations imposed by the support requirements of cemented carbides control the rake angles which can be used.

Texas

Generally, the casting alloys containing principally copper, magnesium or zinc can be machined rapidly and satisfactorily. For these alloys the tools may have smaller rake angles than are required for most of the other alloys; the chips will be small; and there will be little or no tendency for the tools to leave a burr or for chips to build up on the cutting edge. On the other hand, the casting alloys having silicon as the predominant alloying element will machine best if the speeds and cuts are reduced and the rake angles increased.

Arkansas New Mexico

Of the wrought alloys, those which are heat treated to improve their mechanical properties generally have good machining characteristics. The alloy 11S is the most free-machining of the wrought aluminum alloys; it can be machined at high speeds with heavy feeds and small rake angles; the chips are small and the finish is excellent. Those wrought

Tennessee

aluminum alloy products which are not heat treatable, but are dependent upon various amounts of strain-hardening for improvement of their mechanical properties are softer than the heat-treatable wrought alloys. They can be machined most readily by tools having relatively large rake angles. Generally, the greater the amount of strain-hardening prior to machining, the better the machining characteristics of the metal. However, even the softest aluminum, including high purity metal in the annealed temper, may be machined with excellent results when large rake angles are employed and the tools are carefully polished.

GENERAL CHARACTERISTICS OF TOOLS FOR MACHINING ALUMINUM

Although the machining properties of the various alloys differ widely as has been indicated, the following practices, in general, characterize the principal differences between aluminum and most other common metals with respect to the tools required. These practices should, therefore, be carefully observed:

1. Grind more rake on the cutting tools than is common for machining steel.

2. Provide additional space for chips to form and be expelled from the tools.

3. Design tools so that chips and cuttings are directed away from the finished work.

4. Keep cutting edges sharp and free from burrs or wire edges.

5. Maintain smooth, bright, tool face surfaces free from scratches.

6. Employ high machining speeds, moderate feeds and depths of cut.

TOOL MATERIALS

Selection of the most suitable tool material for a particular machining operation is a function from which economies can be realized. Economical use of four general classes of tool materials, which perform satisfactorily in machining aluminum, is discussed in the following paragraphs.

HIGH-CARBON TOOL STEEL

Because of the relatively low cost of plain high-carbon tool steel and the ease with which it can be heat treated, tools can be made from this material at the lowest initial cost. Such tools are adequate for machining a small number of parts or where cutting speeds are necessarily low. Small, fragile tools, such as drills and taps, when made from high-carbon steel, frequently will outperform more expensive tools which break more easily.

HIGH-SPEED STEELS

The abrasive resistance, availability and reasonable cost of high-speed steel tools result in their being used most widely in machining aluminum. These steels permit use of the desired large rake angles. The original 18-4-1 type steel, containing 18 per cent tungsten, 4 per cent chromium, and 1 per cent vanadium, has been used with success in most applications. The more recent development of an 18-4-2 high-speed steel has improved some tools. This steel contains 18 per cent tungsten, 4 per cent chromium, and 2 per cent vanadium. It has a higher carbon content than the 18-4-1 type. The 18-4-2 steels are somewhat more brittle than the 18-4-1 steels but appear to have a higher resistance to abrasion, which makes them suitable for machining aluminum.

The molybdenum high-speed steels, substituted for the tungsten alloys, give as good results as the 18-4-1 steels in most applications. The balanced molybdenum-tungsten type, containing 5.50 per cent molybdenum and 5.50 per cent tungsten, seems to give the best results. However, care must be exercised in their use, as they decarburize more easily than tungsten steels and, unless kept cool, will burn readily during grinding. Tool bits made from cobalt high-speed steels also work well in machining aluminum.

CEMENTED CARBIDES

The principal advantage to be gained from the use of cemented carbide tools, solid or tipped, is the hardness and wear-resistance which they offer. The latter characteristic is particularly advantageous in large production runs. In some cases, the life of carbide-tipped tools has been thirty times that for high-speed steel tools. Aluminum alloys containing large amounts of silicon are quite abrasive, but can be machined advantageously by carbide tools. There are many types of cemented carbides on the market, differing both in composition and in the nature and hardness of the bond. In general, the straight tungsten grades of carbide are used for machining aluminum alloys. Carbide manufacturers should be consulted for their recommendations concerning the proper grade for a specific application. Because of their brittleness, carbide tools should be used only where they can be supported rigidly. Flexibility in the work and intermittent cuts often contribute to breakage of carbide tools.

DIAMONDS

Mounted diamonds are used to accomplish light finishing cuts on aluminum alloys when an extremely high quality of surface finish is required or when extremely accurate dimensional control is desired. Special machine tools are recommended for such work.

TOOL SHAPES

RECOMMENDED shape characteristics of tools for machining aluminum are summarized most readily by referring to the single-point lathe tool shown in Figure 1, next page. The following definitions apply specifically to such a tool, but,

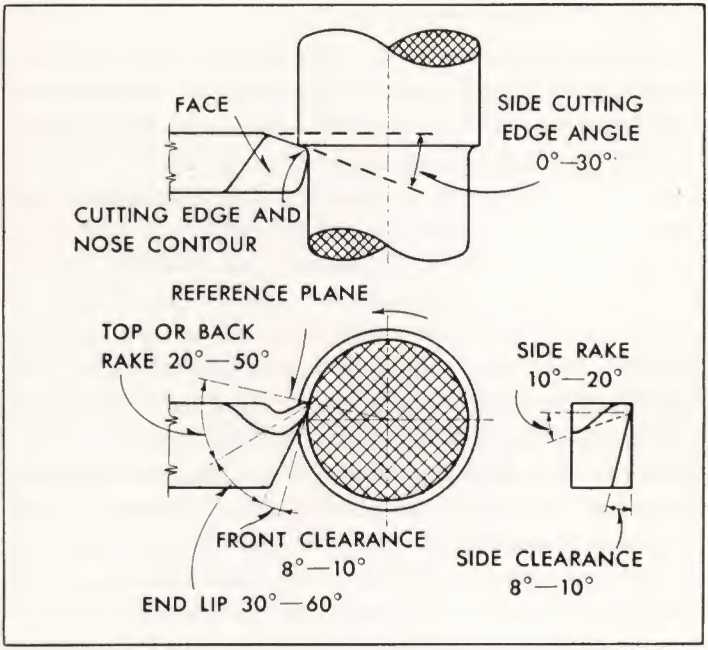


FIGURE 1—*Lathe tool is set at or slightly above center.*

with minor modifications, are applicable to other single- or multiple-tooth tools:

FACE—The surface of the tool over which the chip slides.

CUTTING EDGE—The boundary of the tool face at which the chip is sheared from the work.

REFERENCE PLANE—A radial plane passing through the tip of the tool.

TOP OR BACK RAKE—The angle between the face of the tool and the reference plane as measured in a plane which is perpendicular to the axis of rotation.

SIDE RAKE—The angle between the face of the tool and the

reference plane as measured in a longitudinal plane which is perpendicular to the reference plane.

True Rake—The angle between the face of the tool and the reference plane as measured in a plane which is perpendicular to the cutting edge.

Side Cutting-Edge Angle—The angle between the cutting edge and a perpendicular to the axis of rotation, measured in a horizontal plane.

Front Clearance—The angle between the front clearance surface of the tool and a plane which is tangent to the finished work at the tip of the tool as measured in a plane which is perpendicular to the axis of rotation.

Side Clearance—The angle between the side clearance surface of the tool and a plane which is perpendicular to the axis of rotation as measured in a longitudinal plane which is perpendicular to the reference plane.

Nose Contour—The outline of the cutting edge on the face of the tool.

End Lip Angle—The included angle between the tool face and front clearance surface as measured in a plane perpendicular to the axis of rotation.

Selection of proper tool shapes as defined by the above factors contributes greatly to the successful machining of aluminum alloys. The front and side clearance angles should be about 8° to 10° for carbon and high-speed steel tools and about 6° to 8° for carbide-tipped tools. Tools which are not provided with proper clearance will not perform satisfactorily. If the clearance is too small, the tool will rub against the work and generate heat. If the clearance is too large, the tool may tend to dig into the work, chatter, or fail by chipping at the cutting edge.

The cutting action of the tool is established by the magnitude of the top and side rake angles and the nose contour. The true rake angle results from a combination of all three of these factors and most efficient cutting action is established by the proper control of this angle. This combination also controls the path of the cuttings, which should be away from the finished surface so that the strain-hardened chips will not damage the surface of the work. Round-nosed tools perform very satisfactorily in machining aluminum because they permit the proper variation in true rake at various points along the cutting edge. At the tip of the tool, where the quality of the finish is established, the true rake is equal to the top rake. Along the side edge of the tool, where the excess metal is sliced from the work, the true rake angle is more nearly equal to the side rake angle. The direction of chip flow may also be controlled by varying the side cutting-edge angle. Thus, it is possible to design a tool to remove metal efficiently and also provide a good finish on the work. Varying the true rake angle along the cutting edge also minimizes the possibility of chatter.

A wide range of rake angles must be considered in designing and making tools for machining aluminum alloys because of the relatively large variation in the characteristics of these materials. High-strength and free-machining alloys may be machined satisfactorily with tools, similar to those commonly used for machining steel, in which the rake angles do not exceed 10°. Larger rake angles, in the range 20° to 50°, are required on certain finishing tools and for the aluminum alloys which are not free-cutting. In general, the softer and more ductile the alloy, the larger the required rake angles. The softest materials require tools with exceptionally acute and keen cutting edges.

Tools having large rake angles can be used only on ma-

chines which are sturdy, free from vibration, and which have no lost motion in the feeding mechanism. In using carbide-tipped tools or in some operations involving form tools, it may be necessary to use rake angles smaller than those indicated in the previous paragraph. Negative true rake angles never should be used.

TOOL FINISHES

In all cases it is essential that the faces of tools be provided with extremely smooth surfaces so that the chips will glide over them with the least resistance. These surfaces should be free from grinding-wheel scratches. Cutting edges should be keen and free from burrs or wire edges. Too much emphasis cannot be given to good tool finish, because upon it depends, to a large extent, the success attained in machining aluminum and its alloys. Increase in tool life alone will pay real dividends for time spent in finishing the tools properly. Keen edges and smooth surfaces are best obtained by finish-grinding on a fine or very fine abrasive wheel and then hand-stoning with a very fine oilstone or lapping. Care should be taken so that neither the angles nor the contour of the cutting edge are modified during the finishing operations. Where possible, cemented carbide tools should be diamond-lapped.

TABLE 2

Cuts, Speeds and Feeds When Machining Aluminum Alloys

(See Note)	ROUGH MACHINING			FINISH MACHINING		
	Max. Cut Inches	Speed (f.p.m.)	Feed, Inches	Cut, Inches	Speed (f.p.m.)	Feed, Inches
LATHE TURNING						
Type I castings, not heat treated.	0.25[1]	500 to 1,000	0.020 to 0.030	0.002 to 0.010	Maximum	0.002 to 0.010
All others	0.19[1]	400 to 1,000	0.007 to 0.020	0.002 to 0.010	600 to 1,000	0.002 to 0.010
MILLING						
Type I castings, not heat treated.	0.25	400 to 600 [2] 500 to 700 [3] Maximum [4]	5 to 15[5]	0.010 to 0.020	500 to 700 [2] 500 to 700 [3] Maximum [4]	10 to 25[5]
Type I castings, heat-treated Type II castings Types I and II wrought alloys, heat-treated	0.25	400 to 600 [2] 500 to 700 [3] Maximum [4]	4 to 10[5]	0.010 to 0.020	500 to 700 [2] 500 to 700 [3] Maximum [4]	5 to 15[5]
Type III alloys	0.25	300 to 500 [2]	3 to 8[5]	0.010 to 0.020	500 to 700[2]	4 to 10[5]
BORING						
Light duty (1 to 2 inches)	0.09[1]	Maximum[6]	0.010 to 0.020	0.010 to 0.020[1]	Maximum[6]	0.001 to 0.005
Medium to heavy duty	0.25[1]	600 to 1,000	0.007 to 0.015	0.010 to 0.020[1]	600 to 1,000	0.001 to 0.003
SHAPING						
Heavy duty (36 inches)	0.25	Maximum[7]	0.010 to 0.030	0.005 to 0.010	Maximum[7]	0.100 to 0.150
PLANING	0.38	Maximum[8]	0.025 to 0.100	0.005 to 0.015	Maximum[8]	0.050 to 0.375

Note: See Table I for explanation of Type numbers listed above in first column.
[1] Cut measured on radius.
[2] For carbon steel tools.
[3] For high-speed steel tools.
[4] For cemented carbide tools.
[5] Travel of work.
[6] Peripheral speed of tool is maximum of most machines.
[7] Travel of ram.
[8] Speed of table.

ENGINE LATHE PRACTICE

Consideration should be given to the manner in which the work is supported in the lathe. Because of the high speed at which it should be turned for best performance (see Table 2, page 20, for recommended cuts, speeds and feeds), the work should be held firmly by a chuck, collet or faceplate. The work should be supported in such a manner as to minimize distortion from the action of the chuck or centrifugal force during the turning operation. Use of soft liners between the work and jaw faces will prevent the jaw teeth from marring the surface of the work. The tightness of jaws which expand outward to grip the inside of hollow workpieces should be checked frequently to make sure that thermal expansion of the work is not releasing their grip. Long bars which are introduced through the hollow lathe spindle should be supported on rollers so that whip of the otherwise free end will be eliminated. Ball or roller bearing tailstock centers are more satisfactory than solid, fixed centers in resisting the relatively large end thrusts which sometimes accompany thermal expansion of work being turned between centers.

TURNING TOOLS

For ordinary engine-lathe work a round-nosed tool, as shown in Figure 1, page 16, may be used. General practice is to set the tool at or slightly above center. Sturdy construction of tools and holders is essential to minimize vibration at the high speeds at which aluminum alloys are machined. Although the same tool may often be used for both roughing and finishing cuts, it is important that the cutting edge be restoned before the finishing operation. Figure 1 illustrates a conventional type of solid lathe tool made from rectangular stock. The tool

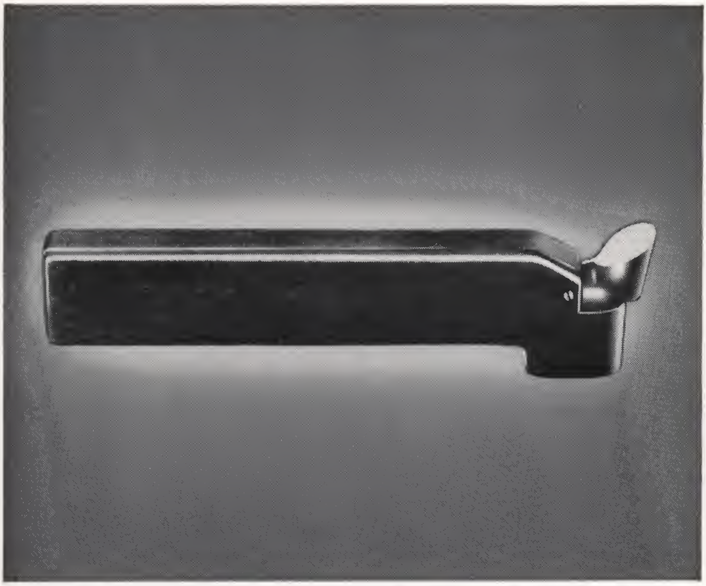


FIGURE 2—*Lathe tool and holder.*

bits used in some of the patented lathe-tool holders also may be ground in accordance with the angles shown in this figure. Figure 2, above, illustrates such a tool and holder.

Another type of tool and holder which possesses certain adjustable features is shown in Figure 3, page 23. The bit of this tool is made from round stock of high-carbon or high-speed steel, or cemented carbide. Resharpening is readily accomplished by holding the bit by its shank in the chuck or collet of a tool grinding machine or engine lathe and grinding off the outside diameter until a keen edge is obtained. After each grinding, the tool should be stoned on the top surface. By using such a tool and following the suggested resharpening procedure, the desired shape may be maintained easily. When the clamp screw of the tool-bit holder is loosened,

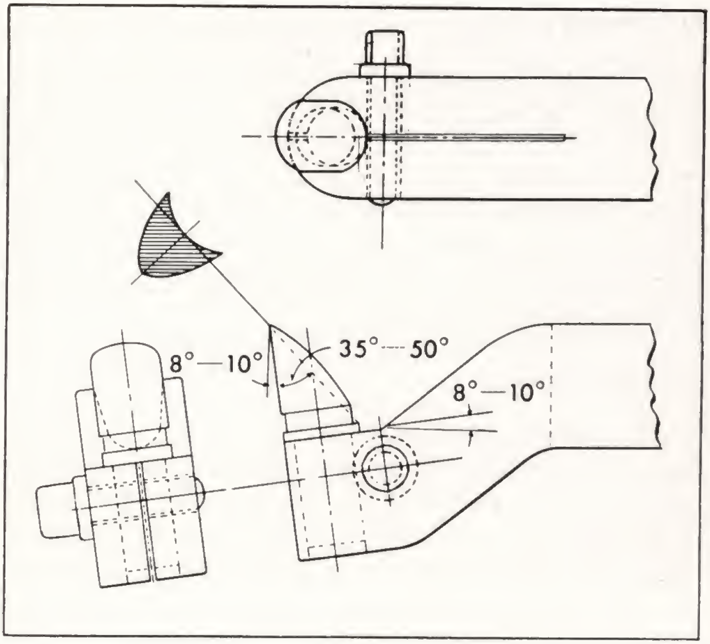


FIGURE 3—*Lathe tool with bit that is easily ground to the proper shape.*

the bit may be turned to various positions, making it adjustable to different working conditions. Tools of this form may be used for both roughing and finishing cuts. This general type of holder, in which the tool bit is supported in a near-vertical position, is being marketed by a number of tool manufacturers, and is particularly advantageous because it permits utilization of large rake angles without weakening the tool bit behind the face. Although the bit shown in Figure 3, above, has a contoured face, similar square or round bits perform very well when the face is flat. Such bits are reground only on the flat face.

PARTING TOOLS

Tools for parting aluminum and its alloys should have from 12° to 20° top rake. Standard front clearance angles of from 8° to 10° may be employed, but side clearance angles of from 2° to 4° are usually sufficient. Providing a front angle of about 15° on parting tools will minimize the size of the teat on the piece as it breaks off. This should not be attempted on thin cutoff blades because the resulting lateral force may cause the parting tool to lead sidewise.

BORING TOOLS

In general, the angles indicated in Figure 1, page 16, should be employed for boring tools, except that the front clearance angle must be larger for small bores; otherwise, the lower portion of the tool may rub the work and prevent the tool from cutting. By proper design of the tool and holder, the tool shown in Figure 3, page 23, may also be adapted to boring operations in an engine lathe or a boring machine.

CUTTINGS

When turning some of the aluminum alloys using a tool with considerable rake, the cuttings may be continuous and slightly curled. Decreasing the rake angles or increasing the feed may tend to curl the cuttings more and cause them to break up. The extent to which this may be done and yet obtain the desired surface finish depends largely upon the alloy being machined. Long continuous cuttings may be objectionable for two reasons; they may foul the tool and machine, and they may also rub over the finished portion of the work and scratch the surface, since they are harder than the stock because of the cold-working they have received during the cutting operation.

When chip control cannot be attained satisfactorily by modifications in rake angle, feed, depth of cut, or tool position, chip breakers of various types may be ground into the face of the tool. They should be used only as a last resort in controlling chips.

Aluminum cuttings from turning, as well as other machining operations, are valuable because they can be reclaimed. Care should be exercised to prevent contamination and, when a premium is paid for controlled purity or composition of scrap, the cuttings from different alloys should be segregated.

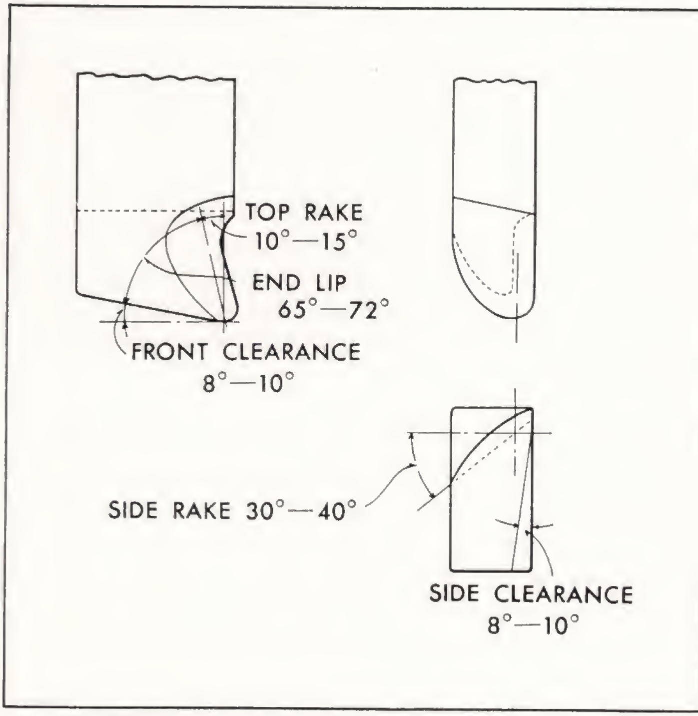


FIGURE 4–*Planer tool for roughing cuts.*

PLANING AND SHAPING

THE INERTIA of the table and ram limit the speed at which aluminum alloys can be cut in a planer or shaper. As the work generally can be anchored securely, heavy feeds and cuts can be taken, which, to some extent, compensate for the low cutting speeds attainable.

A roughing tool is shown in Figure 4, above. It is a sturdy tool with only a moderate amount of rake.

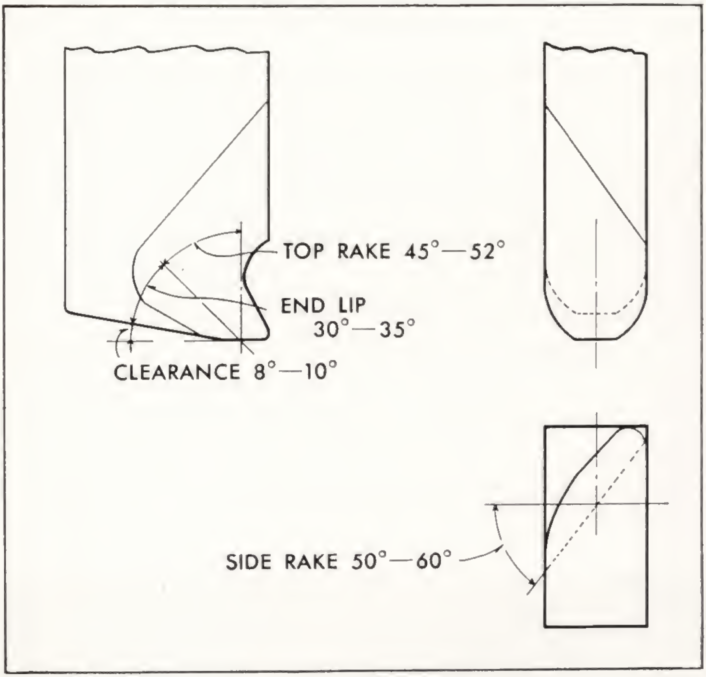


FIGURE 5—*Planer tool for finishing cuts.*

A finishing tool is shown in Figure 5. This has considerable top rake and an extremely large amount of side rake. It gives a long sweep to the cutting edge and produces a decided slicing action which cuts aluminum freely. A finishing tool should be used for light cuts with fine feeds only. Care should be taken to prevent the tool from striking the work on its return stroke. Observance of this precaution keeps the finished work from being marred and also prevents the thin edge of the tool from being injured.

Feeds and cuts at the maximum speed of the equipment are suggested in Table 2, page 20.

MILLING

Milling is probably the most efficient machining method for removing large quantities of excess metal from aluminum parts. Modern milling machines offer rigid construction, high spindle speeds, and are powered by large motors. Desirable high cutting speeds are attained by the speed of the cutter rather than the work. Relatively short chips are produced by the intermittent nature of the cutting action. Carbide-tipped cutters can be used to advantage.

The characteristics of the teeth for all types of milling cutters for the machining of aluminum should correspond, in so far as is practicable, to those for single-point cutting tools previously described. Relatively few teeth should be employed so that ample space is provided for chip formation and so that each tooth actually cuts. Where possible, the

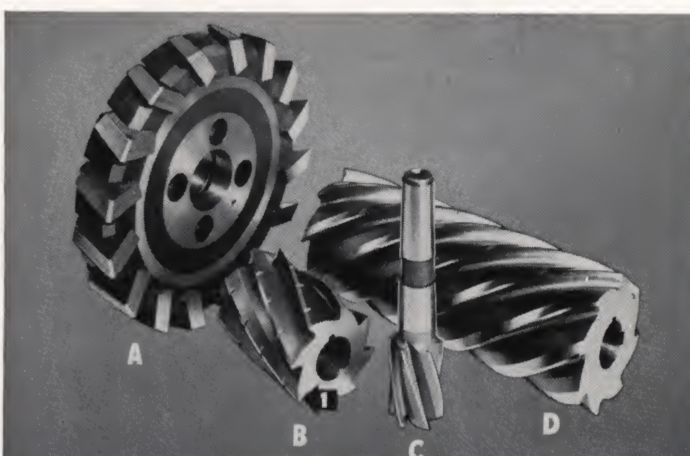


Figure 6–*(A) Inserted-tooth face milling cutter; (B) Spiral nicked-tooth plain milling cutter; (C) End mill for milling aluminum; and (D) Helical milling cutter.*

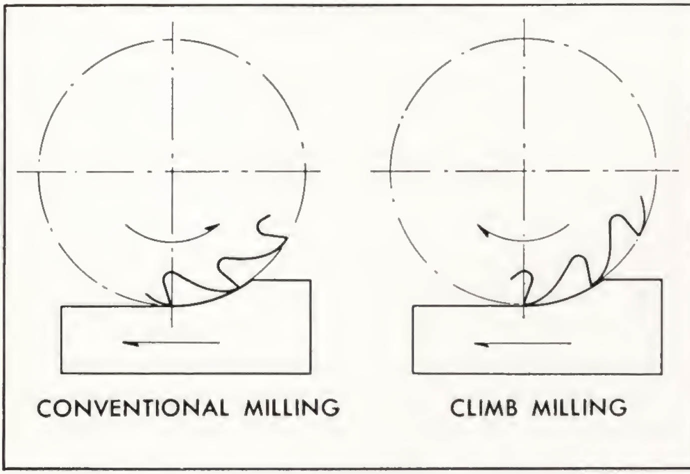


FIGURE 7—*Climb milling offers certain advantages.*

teeth should be designed to afford positive top and side rake. Reported performance of negative rake cutters for milling aluminum has been inconsistent and such cutters are not generally accepted. Primary clearance angles of 5° to 10° are suggested and secondary relief should be provided.

Some typical high-speed steel milling cutters for aluminum are illustrated in Figure 6. Heavy-duty, coarse-tooth plain-type milling cutters with spiral teeth are well suited for machining aluminum. These cutters usually are made with spiral angles ranging from 20° to 30° and the teeth should be undercut to provide a top rake of 10° to 20°. The spiral angle promotes progressive cutting along the cutting edge and the slicing action which results is desirable for the efficient cutting of aluminum. Helical plain milling cutters are made with helix angles of about 50° and they perform satisfactorily on aluminum when the teeth are provided with considerable top rake. If two helical cutters having opposite helix angles are

mounted side by side to balance axial thrust on the spindle and work, the cutting edges should meet at an obtuse angle so that pockets in which chips could pack will not be formed. Nicking the teeth of plain milling cutters in a staggered pattern will cause the chips to be broken into shorter lengths. This practice is helpful but is not always essential for good results.

Milling operations in which the periphery of the cutter is tangent to the finished surface can be accomplished in two manners, as illustrated in Figure 7. In conventional milling, the cutting teeth and the work move in opposite directions. Considerable rubbing occurs when each tooth tries to start a new chip at the finished surface. In climb milling, the cutting teeth move in the same direction as the work and each tooth has positive engagement with the work. Climb milling results in more efficient cutting, less heating of the tool and work, longer tool life and better finish. It should be employed on rigid setups in sturdy milling machines which are free from play in the table and feeding mechanism.

The principles outlined in the preceding paragraph also apply to other types of milling cutters, such as straddle mills, end mills, and face and side milling cutters. These cutters are available in solid or inserted-tooth types.

Aluminum alloys should be milled at relatively high speeds. However, the best combination of cutting speed, feed and cut for a given job depends upon such factors as the type and design of cutter, the kind of tool material used, the sturdiness of the milling machine, its power, and its ability to hold the work securely. The speed at which metal can be removed is limited mostly by the equipment, but extremely high speeds are possible under proper conditions. Speeds, feeds and cuts for milling aluminum alloys, applicable to average shop conditions, are shown in Table 2, page 20.

DRILLING

THE STANDARD type twist drill performs satisfactorily on aluminum but better results can be obtained, especially when drilling soft materials, with drills having a larger spiral angle, that is, more twists per inch. The increased spiral gives more "hook" to the cutting edges, causes the drill to cut more freely and is helpful in removing cuttings in deep drilling operations. Both kinds are illustrated in Figure 8, next page. In general, standard twist drills having 24° to 28° spiral may be used for drilling thin stock or shallow holes. For holes deeper than about six times the drill diameter, a drill with a spiral of 40° to 50° should be used for best results. Twist drills similar to the standard drill, but made with large, deeply cut flutes, with a polished finish, produce excellent results in machining all aluminum alloys. Such drills are used to a considerable extent for deep drilling, and, in the larger sizes, are provided with holes through the length of the drill to permit the forcing of cutting compound to the tip of the drill. These drills do not appear to be as strong as the ordinary twist drill, but less breakage is encountered with them because they cut so freely and the cuttings pass through the flutes so readily.

Speeds for drilling aluminum may range up to 600 peripheral feet per minute with high-speed steel drills and 2,000 feet per minute with carbide-tipped drills. The use of a large number of revolutions per minute for twist drills cannot be overemphasized because the actual cutting speeds in feet per minute are necessarily low on most drilling equipment with the smaller sizes of drills. For instance, a ⅛-inch drill operating at 6,000 rpm has a maximum cutting speed of only 200 feet per minute.

For hand feeding, a light feed is helpful, especially for

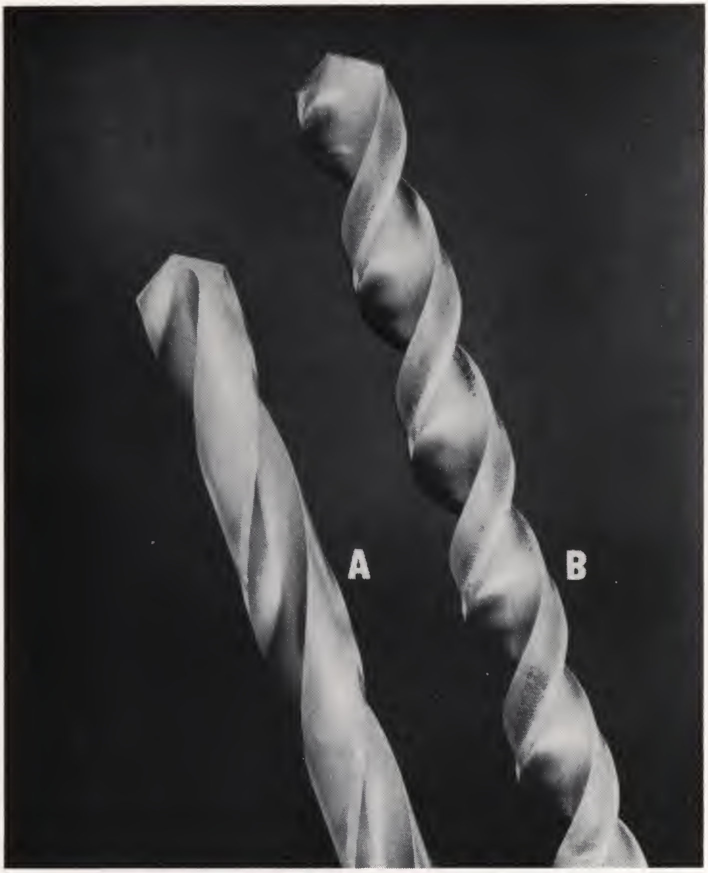


Figure 8—*Twist Drills: (A) Double-fluted or standard twist drill, 24° spiral angle; (B) Special double-fluted twist drill, 47° spiral angle.*

small drills. For power feeds of twist drills of high-speed steel, the feeds may be increased with the diameter of the drill. A feed of 0.004 to 0.012 inch per revolution may be used for drills up to ⅜-inch diameter; 0.006 to 0.020 inch per

revolution for drills $\frac{3}{8}$- to $1\frac{1}{4}$-inch diameter; and 0.016 to 0.035 inch per revolution for those drills over $1\frac{1}{4}$-inch diameter. For carbide-tipped drills, feed rates should be slightly less, in the range 0.004 to 0.030 inch per revolution.

When the work revolves and the drill is stationary, as in a lathe, the straight-fluted drill will sometimes give better results than the spiral-fluted drill.

The standard included cutting-lip angle of 118° at the drill point, as supplied by drill manufacturers, is satisfactory for most jobs. For deep hole drilling, an angle of 130° to 140° facilitates chip removal and minimizes burring. Drills for alloys having a high silicon content should have a sharper point angle of about 90° for greater ease of penetration. The lip clearance angle of 12° to 15° may be increased to as much as 20° when the feed is heavy or when drilling the softer alloys. The clearance should extend from the periphery to the center so that the chisel point is at an angle of 130° to 145° with the cutting edges. Each of the two cutting edges of the drill point should be equal in length and make the same angle with the axis of the drill. Lands and margins should be narrower than on standard twist drills to reduce friction and increase chip space in the flutes.

The web of a twist drill generally increases in thickness toward the shank end. Reducing the web thickness as the drill is ground back will reduce the feeding force. For small diameter drills, "notched-point" thinning, as illustrated in Figure 9, next page, is commonly used.

The notched point is obtained by using the sharp corner of an abrasive wheel, the side of the wheel following the angle of the chisel point. The drill should be held at an angle to the wheel to form a slight rake for the new cutting edge, which is ground to the center of the drill.

On larger drills, notching the point may produce a poor

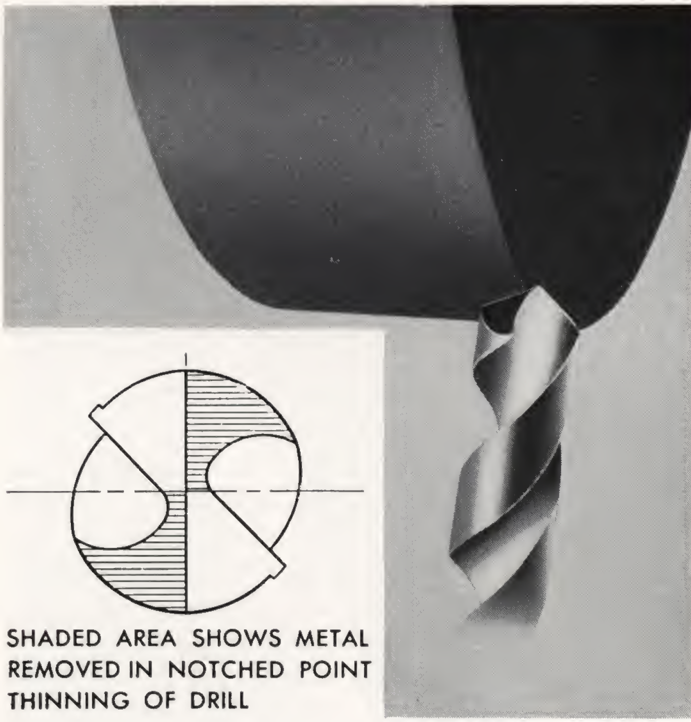


FIGURE 9—*Notched-point thinning of drill point. Used on small diameter drills.*

chip and, therefore, the entire flute is ground at the point. A thin wheel that has been dressed to a radius is used, as illustrated in Figure 10, page 35. The drill is held so that the flute is at an angle to the wheel. Most of the metal should be ground off the back of the land and care must be taken not to grind the rake formed by the spiral angle from the cutting edge or to destroy the shape of the cutting edge. Drills designed especially for drilling aluminum are marketed by a number of the tool manufacturers.

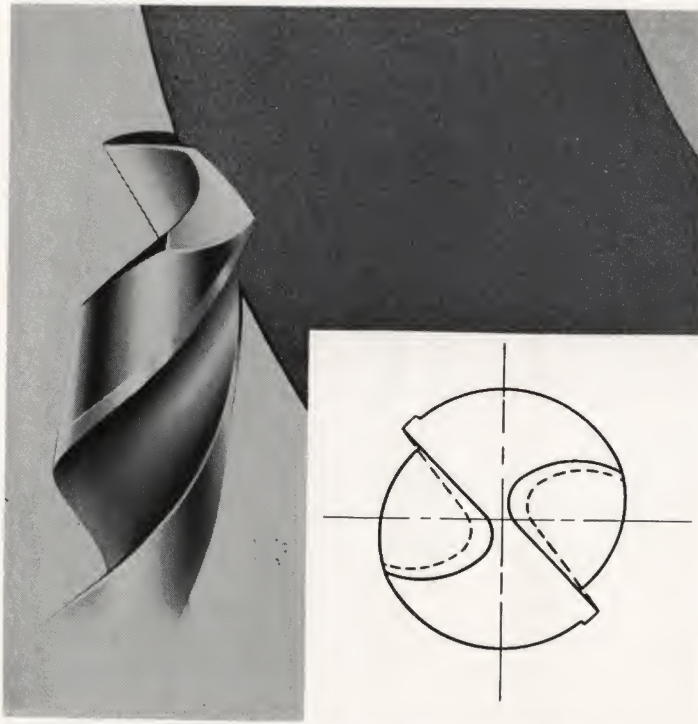


FIGURE 10—*Point-thinning by grinding flute on thin wheel dressed to a radius. For larger drills.*

Thin material often is drilled satisfactorily without the use of cutting compound. A copious quantity of cutting compound, however, should be applied to the drill when drilling deep holes, and it may be necessary to withdraw the drill from the hole occasionally to apply cutting compound to the drill point and to dispose of accumulated cuttings.

If drills break frequently, the trouble may be caused by lack of rigidity in the machine or work, an excessive feed, or improper drill grinding.

FIGURE 11—*Reamers: (A) Plain straight-fluted reamer; (B) Spiral-fluted expansion reamer; (C) Straight-fluted taper reamer; (D) Spiral-fluted taper reamer.*

REAMING

Most of the different types of reamers may be used for aluminum. The flutes may be straight, but spiral flutes frequently produce better results. (See Figure 11.) Flutes spiraled in the direction of rotation of the tool cut freely but feed into the work too rapidly. Therefore, reamers with the spiral opposite to the direction of rotation are preferred; this type cuts more slowly, but the operation can be controlled better. In some instances, special reamers made with the alternate teeth spiraled in opposite directions have been found advantageous.

Reamers for aluminum should have large flutes to pass the chips readily, but the number of teeth should be sufficient to provide adequate support for the tool. A radial rake angle of from 5° to 10° should be used and the clearance behind a very narrow margin should be from 5° to 8°. The cutting edges of reamers should be finished by honing.

Machine reamers less than 2 inches in diameter may be operated at cutting speeds up to 400 feet per minute for reaming straight holes. For tapered holes, speeds up to 300 feet per minute may be used. Holes that are to be reamed should be undersized from 0.006 to 0.016 inch so that the reamer has a definite cutting action. If the hole is too near the finished size, an undesirable burnishing action may result. Very often sufficient attention is not given to boring or drilling operations which prepare the hole for reaming because they are not finishing operations. Use of poorly designed or dull tools in this preliminary operation may work-harden the surface in the hole and thus cause variations in the size of the reamed hole. Use of a cutting fluid (soluble oil, or a mixture of kerosene and lard oil) when reaming at high speed, will assist in minimizing distortion and maintaining size.

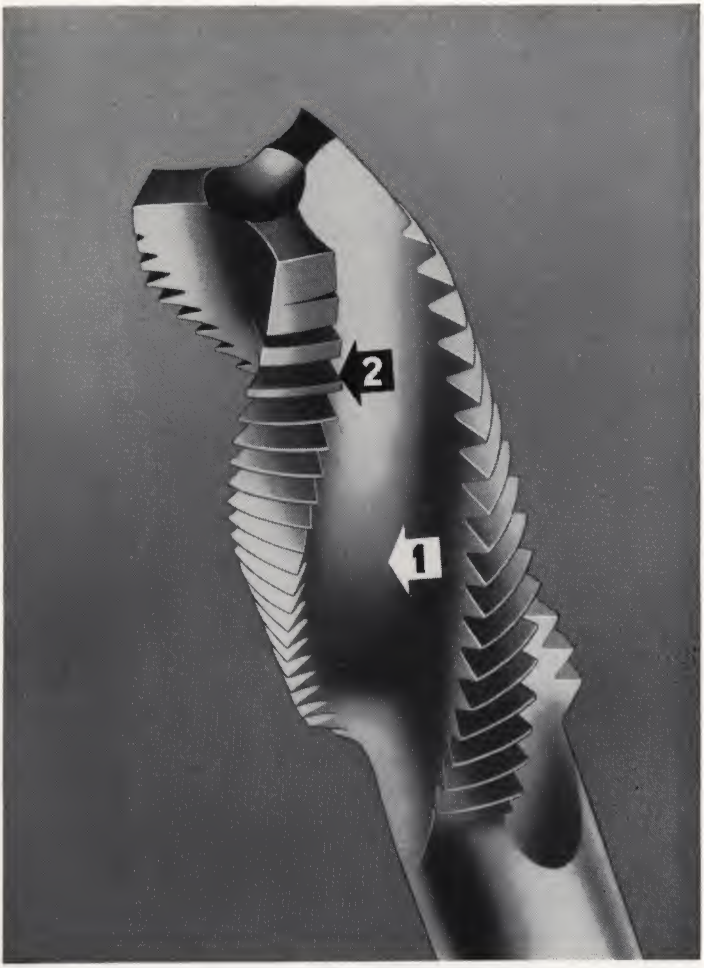


FIGURE 12—*Spiral-fluted tap. (1) Large polished flutes provide easy exit for cuttings. (2) Undercut flutes provide "hook" to cutting edges.*

THREADING

Hand and machine taps of the ground thread type will produce smooth, accurate threads in aluminum when they have flutes that are undercut to provide a top rake of from 10° to 20° at the leading edges. The flutes should be deep and wide to provide chip clearance; taps with small flutes are not very satisfactory because chips may pack in the flutes and cause tap breakage or damage to the threads.

Straight-fluted taps are satisfactory for many aluminum alloys, especially those of Types I and II (Table 1, page 8). Spiral-fluted taps like the one illustrated in Figure 12 may be used for any of the alloys; they are better than straight-fluted taps, especially for tapping soft material. Spiral-fluted taps for cutting right-handed threads should have a right-handed spiral of about the same spiral angle as that used on an ordinary twist drill. Spiral-fluted taps should have a generous taper and this taper should be backed off. Rake on the back face will enable the tap to cut instead of binding when the tap is reversed and will provide a clean thread.

Some taps have a short spiral ground on the front end like the one illustrated in the center of Figure 13, next page. They are known as spiral-pointed or "Gun" taps. This type of tap cuts aluminum alloys freely. Most of the cutting occurs at the end of the tap and the cuttings curl ahead of the tool. It is, therefore, suited only for operations where there is room for the cuttings to be forced ahead of the tool, as in through holes or blind holes that are deep enough for the chips to collect at the bottom. Taps of this type, however, are not suitable for cutting tapered threads or for use as bottom taps.

Thread chasers for self-opening die heads and collapsible taps should be ground with suitable rakes, clearance and chamfer, as shown in Figure 14, page 41. Top rake angle

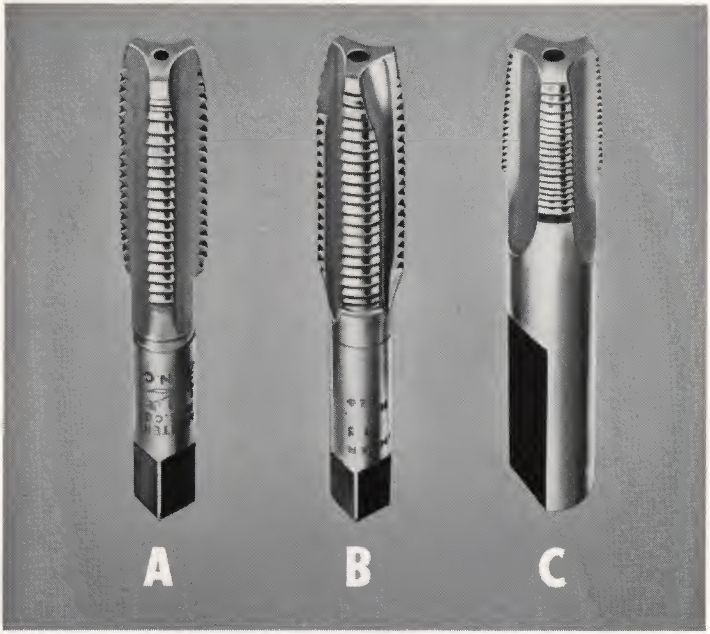


FIGURE 13–*(A) Standard tap; (B) Spiral-pointed screw thread tap; and (C) Pipe thread tap. (All with deep flutes.)*

should be in the higher range for machining soft alloys and in the lower range for harder ones. When selecting this type of equipment, consideration should be given to the disposal of the cuttings, as some tools offer much freer exit for cuttings than others. Provision for lubrication is also important. Fine threads and sharp V's should be avoided in aluminum, particularly the soft alloys, because of the tendency toward seizing. Holes for tapping should be drilled slightly larger than is normal for iron or steel, or a slightly oversized tap should be employed, in order to compensate for the elastic deformation of the metal.

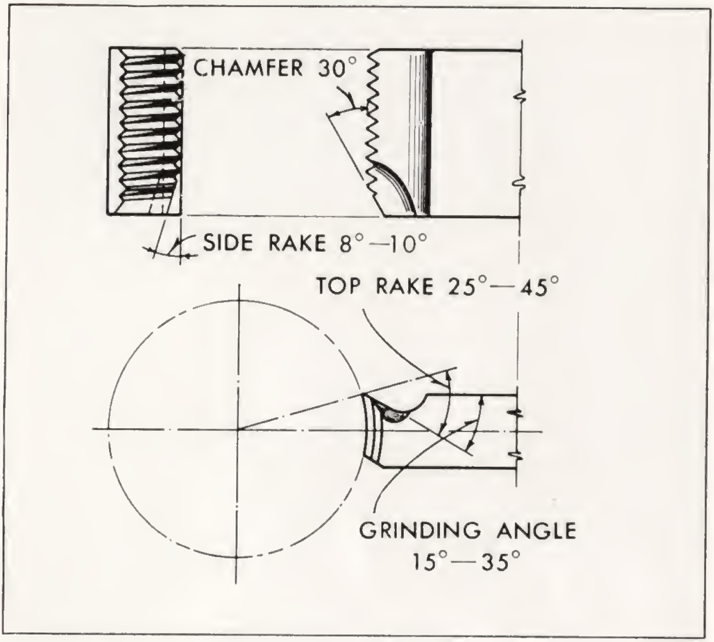


FIGURE 14–*Chasers for self-opening die heads.*

Excellent threads may be chased on an engine lathe even in the softest aluminum, by using a single-pointed threading tool. The top and side rake should be in the lower range indicated previously for lathe tools, and the tool should be properly ground to give the required thread contour. This tool is fed into the work at an angle of 30°, using the compound feed. Speeds for threading and tapping usually range from 40 feet per minute for the harder alloys to 130 feet per minute for the softer alloys. Use of cutting compound in copious amount and under moderate pressure is desirable.

Figure 15—*Bandsawing gates and risers from an aluminum casting.*

SAWING

IT SHOULD be emphasized that the same principles which govern the shape of cutting tools for aluminum should be applied, as far as is practicable, to saws for aluminum. While this statement may seem obvious, experience with sawing equipment indicates that these principles often are overlooked. It is especially important to use comparatively coarse teeth with curved gullets, which are free from sharp corners, burred edges and rough surfaces to which cuttings may adhere. Clearance, although necessarily small, must nevertheless be provided; otherwise, the sides of the teeth will drag and generate heat. Unsatisfactory performance of saw blades employed to cut aluminum frequently can be traced to a lack or loss of clearance.

Circular saw blades with broad teeth are extensively used for aluminum. When such blades are made from semihigh-speed steel, side clearance can be obtained by swaging the teeth so that they are wider than the remainder of the blade. This type of saw blade is used largely for cutoff operations where the cuts are short and intermittent. Clearance on similar solid high-speed steel blades is attained by hollow grinding both sides of the blade. The resulting clearance is more effective and these blades can be used satisfactorily for longer cuts.

Circular saws with chip-breaker teeth perform better than saws having broad teeth. This type of saw, illustrated in Figure 16, next page, has teeth so profiled that the first one cuts deep and the next one cuts wide. Another preferred type of saw blade has alternate side rake teeth. The teeth are arranged, as illustrated in Figure 17, next page, so that the first one cuts on one side and the next one cuts on the opposite side of the saw cut. The teeth should have a side rake of about 15°.

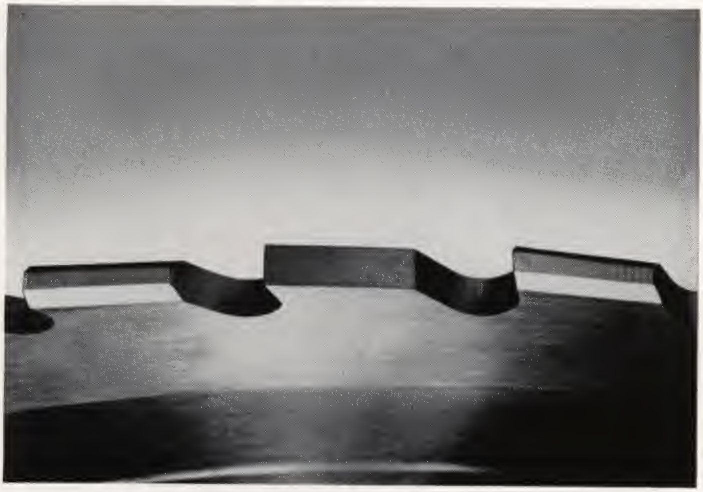
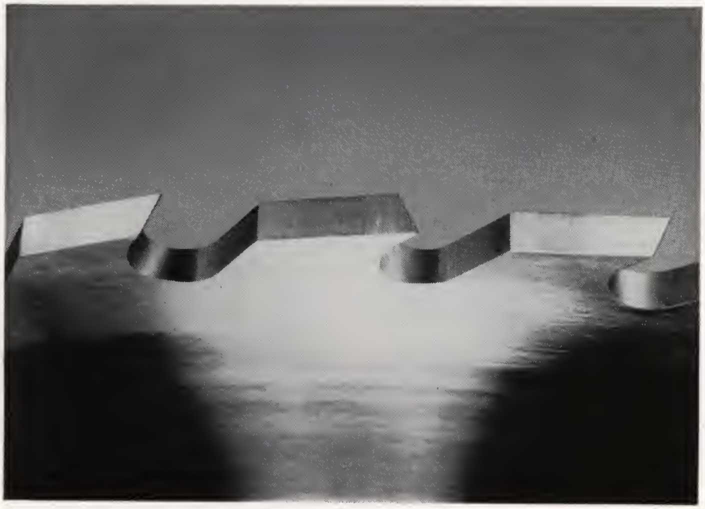


FIGURE 16—*Chip-breaker type saw teeth.*

FIGURE 17—*Alternate side rake type saw teeth.*



Both types of blades can be obtained in the larger sizes with inserted or segmented teeth of high-speed steel or cemented carbides.

For all of these types of circular saw blades, the top rake, or "hook" may vary up to about 45°. The smaller rake angles are used for cutting the harder alloys or when feeding is done by hand. The larger rake angles apply to blades for cutting the softer materials. Obviously, with the use of large rake angles, the sawing machine must be sturdy and free from vibration, and the work must be securely clamped and fed with a positive feeding device. Where it is desired to feed by hand, the saw teeth should have little, if any, top rake; otherwise, the saw will enter the work too rapidly. The teeth on blades for sawing aluminum, however, should never have a negative rake. It is not advisable to employ the alternate side rake on the teeth of very thin blades because of the excessive vibrations and blade "wobble" that would occur.

Circular saw blades for aluminum may be operated satisfactorily at peripheral speeds ranging from 5,000 to 15,000 feet per minute. The lower speeds apply to semihigh-speed steel blades, the intermediate ones to high-speed steel blades and the higher ones to blades with carbide-tipped teeth. The latter blades are being used in increasing numbers, especially in large circular saws for cutting heavy sections.

Bandsawing machines of the high-speed, metal-cutting type perform very satisfactorily in sawing aluminum. Light work can frequently be accomplished in heavy-duty, woodworking bandsawing machines. Blade speeds range from 1,500 to 5,000 feet per minute, but higher speeds have been attained satisfactorily. Removal of the kerf material should be by true cutting action, and "high speed" should not be confused with "friction sawing" which is not recommended for application to aluminum. When high cutting speeds

are used, it is important that the machine be free from vibration and that the butt-welded section of the band be strong, smooth and not thicker than the adjacent parts of the band material.

Bandsaw blades made of spring-tempered steel may be used for light work and may be sharpened readily by filing. For heavy work, the flexible back type of saw with teeth hardened to the bottom of the gullet is preferred. The spacing of the teeth on bandsaws for aluminum should be as coarse as is consistent with the thickness of the material being sawed. Blades having as many as 14 teeth per inch are satisfactory for thin materials. The recent development of so-called "skip-tooth" blades having only 3 teeth per inch are admirably suited to the sawing of heavy aluminum sections. In this type of blade every other tooth is eliminated back to the depth of the gullet for the remaining teeth. Whereas fine feeds should be used with conventional blades to avoid large cuttings, relatively coarse feeds can be used with the skip-tooth blade.

For circular and bandsaws as well as power hacksaws, a cutting lubricant is necessary for most operations involving thick sections. Soluble oil cutting compounds and neutral mineral-base lubricating oils applied to the sides of the blade aid in minimizing friction and gullet clogging. An occasional application of paraffin wax or heavy grease will provide ample lubrication for some work. The life of bandsaw blades, in some instances, has been prolonged considerably by providing a slotted block through which the saw blade passes. This is arranged with a screw-operated grease gun or drip-feed oiler so that the blade is continually passing through the supply of lubricant before entering the work.

Hacksaw blades of the wavy-set type are well suited for cutting aluminum by hand.

BROACHING

ALUMINUM ALLOYS are successfully broached on standard equipment with little trouble. Speeds should be in the upper range of machine capacity and a somewhat greater cut per tooth than is customarily employed with steel should be used. A coarse-tooth pitch is desirable with only two or three teeth in contact and cutting at any one time. In internal finish broaching, best results are obtained if only two teeth are cutting, and, in external broaching, it is often best to have only one finish tooth engaged at one time.

The general principles which apply to single-point tools for aluminum also apply to the individual broach teeth. Rake angles should be 10° to 20°. In external broaching, a side rake of 5° to 20° gives a smooth cutting action, helps to eliminate vibrations, and produces a better finish. Roughing teeth are usually "nicked," which serves to break the chips and avoid clogging the gullets of the tool. Clearance angles should be kept to a minimum, in order to minimize loss of size when the broach is sharpened. Roughing teeth have about 2° clearance and finishing teeth about 1°.

In broaching aluminum, care should be taken that the work is always well supported and rigidly clamped. Broaches should always be kept very sharp; this is particularly essential in broaches for aluminum.

A mineral oil or a mixture of kerosene and lard oil, supplied generously at low pressure, is desirable in broaching aluminum.

ABRASIVE CUTOFF WHEELS

Rubber-bonded abrasive cutoff wheels frequently can be used to advantage for cutting heavy sections of the harder alloys. These wheels perform particularly well when cutting alloys, such as 32S, which are high in silicon content. Smooth, accurate cuts can be produced quickly and cheaply with abrasive cutoff wheels. Manufacturers of the wheels, as well as the equipment in which they are operated, should be consulted for their recommendations for a particular application. Loading is frequently encountered when abrasive wheels are used to cut the softer wrought alloys, but these alloys can be cut quite efficiently by sawing.

FILING

An excellent general-purpose file for aluminum is shown in Figure 18(A). It has coarse, deeply cut, curved teeth. Its pitch of about 10 teeth per inch affords good clearance for the filings; hence, no difficulty is experienced with loading of the teeth. This file removes metal rapidly and also produces a smooth surface. Because of the coarse teeth, it cannot be used for filing small surfaces. Files similar to "A," but with the teeth notched to break up the cuttings, remove metal even more rapidly, but they do not produce quite so smooth a finish. Certain other modifications of this file, with double-cut teeth (more like those of a rasp), have been found unsatisfactory, in that they cut poorly and produce a rough surface.

The long-angle lathe file, illustrated in Figure 18(B), is excellent for finish-filing aluminum. It has finer teeth than those of file "A," which reduce the tendency to "run off." Files of this type may have a pitch of 14 to 20 teeth per inch,

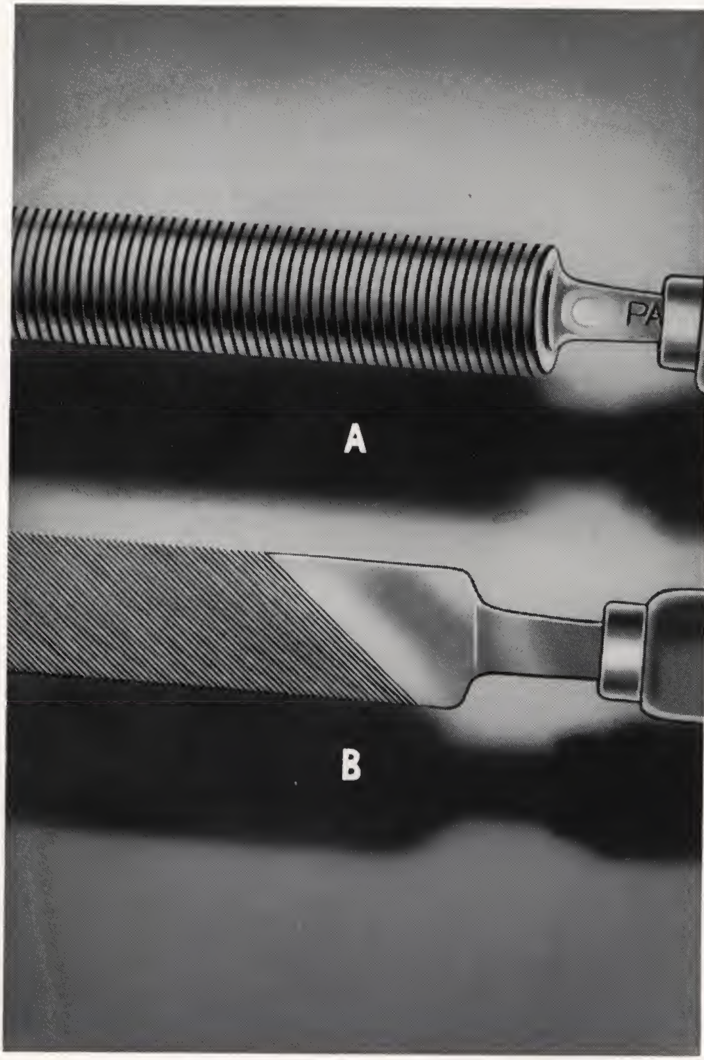


FIGURE 18—*Files: (A) Deeply cut, coarse tooth file; (B) Long-angle lathe file.*

and the teeth should be cut to a side rake angle of about 45° to 55°. The side rake angle provides a more efficient cutting action by producing a slicing motion. Because of the large angle of the teeth, the direction of motion of the file is effective in driving the cuttings from the teeth.

Files with single-cut fine teeth do not work well on aluminum, because the cuttings stick in the teeth. Those with double-cut teeth, whether fine or coarse, are no better on soft materials, but perform fairly well on the harder materials. A double-cut file having the basic cut quite coarse and the overcut much finer, is excellent for rapid stock removal, but does not give a good finish. Ordinary files with single-cut coarse teeth may be made to perform nearly as well as the long-angle lathe file, by employing a side-sweep motion instead of one in the direction of the length of the file. Various types of files designed specifically for filing aluminum are available from several of the file manufacturers. Files with coarse or medium-coarse teeth, single cut, are better if used with oil. Chalk rubbed over the teeth also helps to prevent loading. File cards should be used frequently to remove the strain-hardened chips from the teeth so that they do not damage the finished surface.

Where rifflers are used, they should have coarse teeth. Rotary files and burrs should be spiral-cut. Abrasive disks, drums, and belts of various grits are often used to impart the desired finish.

CUTTING SPEEDS, FEEDS, AND POWER REQUIREMENTS

Wide ranges of cutting speeds and feeds may be used in machining aluminum, but best results are generally obtained by employing high speeds, moderate feeds and depths of cut. Table 2, page 20, presents approximate values for these variables as are applicable to the average shop. Selection of particular values for speed, feed, and cut depths usually is dependent upon the character of work, type of tool, cutting compound, and characteristics of the machine in which the work is being done. The rate at which the excess aluminum can be removed is more a function of machine tool limitations than machining characteristics of the metal itself.

Milling cutters, as well as single-point lathe tools, have been used at cutting speeds approaching 20,000 feet per minute without any indication of even this speed being an upper limit as far as the machining characteristics of aluminum are concerned. These phenomenal machining speeds and the correspondingly high rates of metal removal can be utilized only in machine tools that have heavy, sturdy construction and are balanced properly to operate smoothly at the high speeds. More power than is usually available in standard machine tools could be utilized to good advantage. From 2 to 7 cubic inches of aluminum per minute can be removed from the work for each horsepower that is available. Values in the upper end of this range apply when the material is relatively low in shear strength, when the feed is great, or when the tools have large rake angles. The lower values prevail when the rate of speed is small, when the shear strength of the material is high, or when relatively inefficient metal removal operations, such as drilling, are employed.

CUTTING COMPOUNDS

DRY MACHINING operations are often accomplished satisfactorily on aluminum when the speeds are great and the feeds and cuts are moderate. Most of the generated heat leaves with the chips, and the work and tools remain cool. When heavy cuts and feeds produce excessive heat, however, a cutting compound should be used, and often the type of compound that is essentially a coolant will produce the best results. For this purpose, soda water or a lean, soluble oil solution is generally employed and, in some instances, it may be desirable to add a small amount of lard oil or kerosene. This type of compound is widely used for milling, drilling and sawing operations.

Where the cutting compound must have more definite lubricating characteristics, the following suggestions apply:

1. Straight mineral oils having a viscosity of about 60 seconds Saybolt universal at 100°F are relatively inexpensive and yield good results.

2. Additions of from 5 to 10 per cent of a fatty oil, such as lard oil, will improve the performance of the straight mineral oil.

3. Special oils have been produced by many of the oil companies for use as a lubricant when aluminum is being machined. Most of these proprietary oils give excellent results.

4. Another excellent lubricant consists of equal parts of lard oil and kerosene, but the proportions may be varied over a wide range for different operations.

5. Heavy cuts and feeds as encountered in heavy roughing cuts and tapping operations require the use of higher viscosity lubricants.

GRINDING

THE HARDER free-cutting aluminum alloys may be ground satisfactorily with free-cutting commercial silicon-carbide grinding wheels, such as Crystolon, Carborundum and Natalon. Aluminous abrasives from No. 14 to No. 36 generally are preferred for rough grinding work. Resin-bonded wheels of medium hardness and grit sizes of 24 to 30 also have been found to be satisfactory for rough grinding operations. Finish-grinding operations can be accomplished satisfactorily by use of a softer vitrified bonded silicon-carbide wheel having a somewhat smaller grit size. The assistance of the wheel supplier should be obtained in selecting the proper grade of each commercial make of wheel.

Once a grinding wheel has been selected, there are three variables that affect the quality of a finish, namely, wheel speed, work speed and grinding compound. Wheel speeds of about 6,000 feet per minute have given good results, but both wheel and work speeds can best be set by the experienced operator according to his own good judgment. A solution of soluble cutting oil and water works well as a grinding compound. It is important that the fine grindings of aluminum be strained from the compound before re-using, in order to prevent deep scratches on the finished surface.

The soft alloys cause the grinding wheel to clog and require generous use of a grease stick. Furthermore, special care may be required in grinding castings and wrought alloy products that have been heat treated. Their greater resistance to cutting generates a considerable amount of heat which, in turn, may cause warping and render the maintenance of dimensions difficult.

TABLE 3—Mechanical Finishing of Aluminum Alloys

	ROUGHING			Greasing or Oiling	Buffing	Coloring	Finish[1] Grinding
	Solid Wheel	Cloth Belt	Sewed Muslin				
Abrasive	Al_2O_3 or SiC	Al_2O_3	Al_2O_3	Turkish Emery	Tripoli	Fine Lime or Soft Silica	SiC
Carrier	Solid Wheel	Cloth Belt	Sewed Muslin Buffs	Sewed Muslin Buffs	Pocketed Muslin Buffs	Open Muslin or Flannel	Solid Wheel
Grit	16 to 100	46 to 300	46 to 80	120 to 240			30 to 40
Bond	Phenolic Resin	Glue	Glue	Glue			Vitrified
Hardness	Medium		Medium	Medium	Soft	Very Soft	Soft
Peripheral Speed of Wheel, feet per minute	6,000 to 12,000	3,000	6,000	6,000	7,000 to 8,000	3,000 to 4,000	6,000 to 7,000
Lubricant	Dry or Grease	Grease or Kerosene	Grease	Grease	Grease		Soluble Oil 1 to 35 or 40

[1] Mechanical finish applied to castings—to be preceded by machining.

FINISHES

Smooth, lustrous finishes may be produced on aluminum and most of its alloys by the application of proper machining procedures. By employing the roughing, greasing, buffing and coloring procedures outlined in Table 3, brightly polished surfaces may be produced. Other effective mechanical

finishes include sandblasting, scratchbrushing and peening. Aluminum may also be finished by the use of chemical solutions and by electrochemical processes, such as the patented Alumilite* process. The hard, wear-resistant aluminum oxide coating produced by this process does have some thickness. Allowance should be made for this thickness in machining close-fitting parts. Generally, however, if the parts are kept on the low side of tolerance on outside diameters and on the high side of tolerance on inside diameters, the allowance will be sufficient to compensate for the coating.

Paint, lacquer and enamel also are applicable to aluminum. For more complete information on the subject of finishing, write to Aluminum Company of America.

Suggested practices for machining aluminum in automatic screw machines are covered in another booklet, *Alcoa Aluminum in Automatic Screw Machines,* which is available upon request.

*A trade name of Aluminum Company of America

TABLES OF
MECHANICAL PROPERTIES

TABLE 4

Typical[1] Mechanical Properties of Wrought Aluminum Alloys

Alloy and Temper	Tensile Strength, Lb./Sq. In.	Yield Strength (Offset = 0.2%), Lb./Sq. In.	Elongation, Per Cent in 2 Inches		Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,(2) Lb./Sq. In.
			Sheet Specimen (1/16 Inch Thick)	Round Specimen (1/2 Inch Diameter)			
BD1S-O	10,000	4,000	43	..	19	7,000	3,000
BD1S-H12	12,000	11,000	16	..	23	8,000	4,000
BD1S-H14	14,000	13,000	12	..	26	9,000	5,000
BD1S-H16	16,000	15,000	8	..	30	10,000	6,000
BD1S-H18	19,000	18,000	6	..	35	11,000	6,500
EC-O	12,000	4,000	..	(3)	..	......	......
EC-H19	27,000	24,000	..	(3)	..	......	7,000
2S-O	13,000	5,000	35	45	23	9,500	5,000
2S-H12	15,500	14,000	12	25	28	10,000	6,000
2S-H14	17,500	16,000	9	20	32	11,000	7,000
2S-H16	20,000	18,000	6	17	38	12,000	8,000
2S-H18	24,000	22,000	5	15	44	13,000	8,500
3S-O	16,000	6,000	30	40	28	11,000	7,000
3S-H12	19,000	17,000	10	20	35	12,000	8,000
3S-H14	21,500	19,000	8	16	40	14,000	9,000
3S-H16	25,000	22,000	5	14	47	15,000	9,500
3S-H18	29,000	26,000	4	10	55	16,000	10,000
Alclad 3S	Properties substantially same as 3S						
4S-O	26,000	10,000	20	25	45	16,000	14,000
4S-H32	31,000	22,000	10	17	52	17,000	15,000
4S-H34	34,000	27,000	9	12	63	18,000	16,000
4S-H36	37,000	31,000	5	9	70	20,000	17,000
4S-H38	40,000	34,000	5	6	77	21,000	18,000
Alclad 4S	Properties substantially same as 4S						
11S-T3 (4)	55,000	48,000	..	15	95	32,000	18,000
11S-T6	57,000	39,000	..	17	97	34,000	18,000
11S-T8	59,000	45,000	..	12	100	35,000	18,000
14S-O	27,000	14,000	..	18	45	18,000	13,000
14S-T4	62,000	40,000	..	20	105	38,000	20,000
14S-T6	70,000	60,000	..	13	135	42,000	18,000
Alclad 14S-O	25,000	10,000	21	..	..	18,000	......
Alclad 14S-T3	63,000	40,000	20	..	..	37,000	......
Alclad 14S-T4	61,000	37,000	22	..	..	37,000	......
Alclad 14S-T6	68,000	60,000	11	..	..	41,000	......
17S-O	26,000	10,000	..	22	45	18,000	13,000
17S-T4	62,000	40,000	..	22	105	38,000	18,000
A17S-T4	43,000	24,000	..	27	70	28,000	13,500
18S-T61	61,000	46,000	..	12	120	39,000	17,000
B18S-T72	48,000	37,000	..	11	95	30,000	......
24S-O	27,000	11,000	19	22	47	18,000	13,000
24S-T3	70,000	50,000	18	..	120	41,000	20,000
24S-T4	68,000 (5)	48,000 (5)	20	19	120	41,000	20,000
24S-T36	72,000	57,000	14	..	130	42,000	18,000
Alclad 24S-O	26,000	11,000	19	..	..	18,000	......
Alclad 24S-T3	64,000	44,000	18	..	..	40,000	......
Alclad 24S-T4	64,000	42,000	19	..	..	40,000	......

TABLE 4—*Concluded*

Typical[1] Mechanical Properties of Wrought Aluminum Alloys

Alloy and Temper	Tensile Strength, Lb./Sq. In.	Yield Strength (Offset = 0.2%), Lb./Sq. In.	Elongation, Per Cent in 2 Inches		Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit,(2) Lb./Sq. In.
			Sheet Specimen (1/16 Inch Thick)	Round Specimen (1/2 Inch Diameter)			
Alclad 24S-T36	67,000	53,000	11	..	..	41,000	......
Alclad 24S-T81	65,000	60,000	6	..	..	......	......
Alclad 24S-T86	70,000	66,000	6	..	..	......	......
25S-T6	58,000	37,000	..	19	110	35,000	18,000
32S-T6	55,000	46,000	..	9	120	38,000	16,000
B50S-O	21,000	8,000	24	..	36	14,000	12,500
B50S-H32	24,500	21,000	9	..	45	16,000	......
B50S-H34	27,500	24,000	8	..	50	17,000	16,000
B50S-H36	29,500	26,000	7	..	54	18,000	17,000
B50S-H38	31,000	28,000	6	..	57	19,000	18,000
A51S-T6	48,000	43,000	..	17	100	32,000	11,000
52S-O	27,000	12,000	25	30	45	18,000	16,000
52S-H32	34,000	27,000	12	18	62	20,000	17,000
52S-H34	37,000	31,000	10	14	67	21,000	18,000
52S-H36	39,000	34,000	8	10	74	23,000	19,000
52S-H38	41,000	36,000	7	8	85	24,000	20,000
53S-O	16,000	8,000	..	35	26	11,000	8,000
53S-T4	30,000	20,000	..	21	62	18,000	13,000
53S-T5	27,000	21,000	..	15	60	17,000	......
53S-T6	37,000	32,000	..	13	80	23,000	13,000
56S-O	42,000	22,000	..	35	..	26,000	20,000
56S-H18	63,000	59,000	..	10	..	34,000	22,000
56S-H38	60,000	50,000	..	15	..	32,000	......
61S-O	18,000	8,000	22	30	30	12,500	9,000
61S-T4	35,000	21,000	22	25	65	24,000	13,500
61S-T6	45,000	40,000	12	17	95	30,000	13,500
62S-O	17,000	6,500	..	30	28	12,000	8,500
62S-T4	35,000	21,000	..	25	65	24,000	13,500
62S-T6	45,000	40,000	..	17	95	30,000	13,500
63S-T42	22,000	13,000	20	..	42	14,000	9,500
63S-T5	27,000	21,000	12	..	60	17,000	9,500
63S-T6	35,000	31,000	12	..	73	22,000	9,500
63S-T83	38,000	36,000	10	..	82	......	......
63S-T831	32,000	29,000	10	..	70	......	......
63S-T832	45,000	40,000	10	..	95	......	......
75S-O	33,000	15,000	17	16	60	22,000	......
75S-T6	82,000 (6)	72,000 (6)	11	11	150	49,000	24,000
Alclad 75S-O	32,000	14,000	17	..	..	22,000	......
Alclad 75S-T6	76,000	67,000	11	..	..	46,000	......

[1] The values given in this table are averages which take into account the variations introduced by size, shape or method of manufacture. For guaranteed minimum values, see the Alcoa booklet, "Alcoa Aluminum and Its Alloys," Tables 30 through 41.

[2] Based on 500 million cycles of completely reversed stress using the R. R. Moore type machine and specimen.

[3] This material is commonly used in wire sizes for which the typical elongation in 10 inches is about 23% for EC-O and 1.5% for EC-H19.

[4] For sizes up to 1½ inches. For larger sizes, the strengths will be somewhat lower.

[5] The strengths of extrusions more than about ¾ inch thick will be 15 to 20% higher.

[6] Extrusions will have strengths about 8 to 10% higher.

TABLE 5—Mechanical Properties of Aluminum Sand-Casting Alloys[1]

Alloy	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tensile Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Tensile Strength, Lb./Sq. In.	Tensile Yield Strength (Offset =0.2%), Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Compressive Yield Strength(2) (Offset =0.2%), Lb./Sq. In.	Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit, R. R. Moore Type Specimen; 500,000,000 Cycles, Lb./Sq. In.
43	17,000	3.0	19,000	8,000	8.0	9,000	40	14,000	8,000
108	19,000	1.5	21,000	14,000	2.5	15,000	55	17,000	11,000
113	19,000	(3)	24,000	15,000	1.5	16,000	70	20,000	9,000
122-T61	30,000	(3)	41,000	40,000	(5)	43,000	115	32,000	8,500
142-T21	23,000	(3)	27,000	18,000	1.0	18,000	70	21,000	6,500
142-T571	29,000	(3)	32,000	30,000	0.5	34,000	85	26,000	......
142-T77	21,500	(3)	30,000	23,000	2.0	24,000	75	24,000	10,500
195-T4 (4)	29,000	6.0	32,000	16,000	8.5	17,000	60	26,000	7,000
195-T6	32,000	3.0	36,000	24,000	5.0	25,000	75	30,000	7,500
195-T62	36,000	(3)	40,000	34,000	1.5	36,000	95	32,000	8,000
212	19,000	(3)	23,000	14,000	2.0	14,000	65	20,000	9,000
214	22,000	6.0	25,000	12,000	9.0	12,000	50	20,000	7,000
B214	17,000	(3)	20,000	13,000	2.0	14,000	50	17,000	......
F214	17,000	(3)	21,000	12,000	3.0	13,000	50	17,000	......

TABLE 5 *Concluded*—Mechanical Properties of Aluminum Sand-Casting Alloys[1]

Alloy	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tensile Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Tensile Strength, Lb./Sq. In.	Tensile Yield Strength (Offset = 0.2%), Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Compressive Yield Strength(2) (Offset = 0.2%), Lb./Sq. In.	Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit, R. R. Moore Type Specimen; 500,000,000 Cycles, Lb./Sq. In.
220-T4	42,000	12.0	46,000	25,000	14.0	26,000	75	33,000	8,000
319-F	23,000	(3)	27,000	18,000	2.0	19,000	70	22,000	10,000
319-T6	31,000	1.5	36,000	24,000	2.0	25,000	80	29,000	10,000
355-T51	25,000	(3)	28,000	23,000	1.5	24,000	65	22,000	7,000
355-T6	32,000	2.0	35,000	25,000	3.0	26,000	80	28,000	9,000
355-T61	36,000	(3)	39,000	35,000	1.0	37,000	90	31,000	9,500
355-T7	35,000	(3)	38,000	36,000	0.5	38,000	85	28,000	10,000
355-T71	30,000	(3)	35,000	29,000	1.5	30,000	75	26,000	10,000
356-T51	23,000	(3)	25,000	20,000	2.0	21,000	60	20,000	7,500
356-T6	30,000	3.0	33,000	24,000	3.5	25,000	70	26,000	8,500
356-T7	31,000	(3)	34,000	30,000	2.0	31,000	75	24,000	9,000
356-T71	25,000	3.0	28,000	21,000	3.5	22,000	60	20,000	......
A612	32,000 (6)	2.0 (6)	35,000 (7)	25,000 (7)	5.0 (7)	......	75 (7)	......	8,000

[1] Tension and hardness values obtained from standard half-inch diameter tensile test specimens, individually cast in green sand molds, and tested without machining off the surface. The modulus of elasticity varies somewhat with the alloy, but an average value of 10,300,000 psi can be used for most calculations.

[2] Results of tests on specimens having an l/r ratio of 12.

[3] Not required. The error in determining elongations of 1% or less is comparable with the value being measured.

[4] On standing at room temperature for several weeks, the properties will approach those of the T6 condition.

[5] Less than 0.5%.

[6] Based on tests made from 5 to 7 days after casting.

[7] From tests made approximately 30 days after casting.

TABLE 6—Mechanical Properties of Aluminum Permanent-Mold Casting Alloys[1]

Alloy	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tensile Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Tensile Strength, Lb./Sq. In.	Tensile Yield Strength (Offset = 0.2%), Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Compressive Yield Strength(2) (Offset = 0.2%), Lb./Sq. In.	Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit, R. R. Moore Type Specimen; 500,000,000 Cycles, Lb./Sq. In.
43	21,000	5.0	23,000	9,000	10.0	9,000	45	16,000	......
A108	24,000	(3)	28,000	16,000	2.0	17,000	70	22,000	......
113	24,000	(3)	28,000	19,000	2.0	20,000	70	22,000	......
C113	25,000	(3)	30,000	24,000	1.0	25,000	80	24,000	9,500
122-T551	30,000	(3)	37,000	35,000	(5)	40,000	115	30,000	8,500
122-T65	40,000	(3)	48,000	36,000	(5)	36,000	140	36,000	9,000
A132-T551	31,000	(3)	36,000	28,000	0.5	28,000	105	28,000	13,500
A132-T65	40,000	(3)	47,000	43,000	0.5	43,000	125	36,000	......
D132-T5	31,000	(3)	36,000	28,000	1.0	28,000	105	28,000	13,500
138	26,000	(3)	30,000	24,000	1.5	30,000	100	24,000	......
142-T571	34,000	(3)	40,000	34,000	1.0	34,000	105	30,000	10,500
142-T61	40,000	(3)	47,000	42,000	0.5	44,000	110	35,000	9,500
B195-T4 (4)	33,000	4.5	37,000	19,000	9.0	20,000	75	30,000	9,500
B195-T6	35,000	2.0	40,000	26,000	5.0	26,000	90	32,000	10,000
B195-T7	33,000	3.0	39,000	20,000	4.5	20,000	80	30,000	9,000
A214	22,000	2.5	27,000	16,000	7.0	17,000	60	22,000	......

TABLE 6 *Concluded*—Mechanical Properties of Aluminum Permanent-Mold Casting Alloys[1]

Alloy	Minimum Values for Specifications		TYPICAL VALUES (Not Guaranteed)						
	Tensile Strength, Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Tensile Strength, Lb./Sq. In.	Tensile Yield Strength (Offset = 0.2%), Lb./Sq. In.	Elongation, Per Cent in 2 Inches	Compressive Yield Strength(2) (Offset = 0.2%), Lb./Sq. In.	Brinell Hardness, 500-kg. Load 10-mm. Ball	Shearing Strength, Lb./Sq. In.	Endurance Limit, R. R. Moore Type Specimen; 500,000,000 Cycles, Lb./Sq. In.
333-F	28,000	(3)	34,000	19,000	2.0	19,000	90	27,000	14,500
333-T5	30,000	(3)	34,000	25,000	1.0	25,000	100	27,000	12,000
333-T6	35,000	(3)	42,000	30,000	1.5	30,000	105	33,000	15,000
333-T7	31,000	(3)	37,000	28,000	2.0	28,000	90	28,000	12,000
355-T51	27,000	(3)	30,000	24,000	2.0	24,000	75	24,000	......
355-T6	37,000	1.5	43,000	27,000	4.0	27,000	90	34,000	10,000
355-T62	42,000	(3)	45,000	40,000	1.5	40,000	105	36,000	10,000
355-T7	36,000	(3)	40,000	30,000	2.0	30,000	85	30,000	10,000
355-T71	34,000	(3)	36,000	31,000	3.0	31,000	85	27,000	10,000
356-T6	33,000	3.0	40,000	27,000	5.0	27,000	90	32,000	13,000
356-T7	29,000	4.0	33,000	24,000	5.0	24,000	70	25,000	11,000
C612	28,000 (6)	7.0 (6)	35,000 (7)	18,000 (7)	8.0 (7)	......	70 (7)	......	......
750-T5	18,000	8.0	20,000	8,500	10.0	8,500	45	13,000	9,000

[1] Tension and hardness values obtained from standard half-inch diameter tensile test specimens, individually cast in a permanent mold, and tested without machining off the surface. The modulus of elasticity varies somewhat with the alloy, but an average value of 10,300,000 psi can be used for most calculations.

[2] Results of tests on specimens having an l/r ratio of 12.

[3] Not required. The error in determining elongations of 1% or less is comparable with the value being measured.

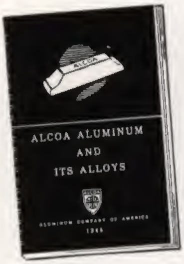
[4] On standing at room temperature for several weeks, properties approach those of the T6 condition.

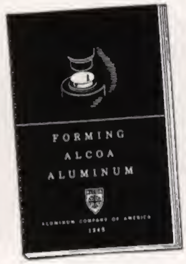
[5] Less than 0.5%.

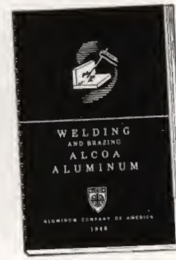
[6] Based on tests made from 5 to 7 days after casting.

[7] From tests made approximately 30 days after casting.

Other Literature in the Alcoa Library







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Handbook of design considerations as they affect economy, strength and production of die castings. Profusely illustrated with 170 comprehensive figures and photographs. 190 pages.

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Fundamental information concerning the alloys produced by Aluminum Company of America. 179 pages. 25 illustrations. 107 data-packed tables.

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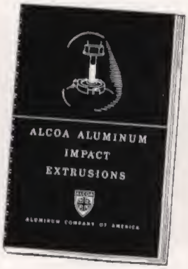
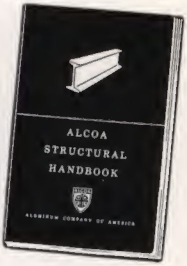
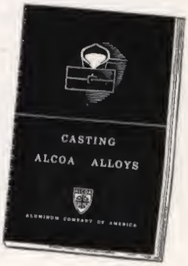
ALUMINUM COMPANY OF AMERICA

of Helpful Information on Aluminum







RIVETING ALCOA ALUMINUM

Information on riveting aluminum, strength and proportions of riveted joints, driving methods, and alloy selection. 84 pages. 32 tables. 16 illustrations.

ALCOA ALUMINUM IN AUTOMATIC SCREW MACHINES

Information on machining aluminum on automatic screw machines, to help the operator understand general practices, proper tools, speeds, feeds and angles. 99 pages. 22 tables. 31 illustrations.

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This helpful booklet for the designer explains the impact extrusion process and describes the factors affecting design. Includes pictures of a number of typical applications. 48 pages. 5 tables. 37 illustrations.

ALCOA STRUCTURAL HANDBOOK

Section elements of various structural shapes produced in Alcoa aluminum, together with strength data on members fabricated in the various alloys. Discussions, examples, figures and tables. 214 pages.

CASTING ALCOA ALLOYS

Description of the various aluminum casting alloys. Considerations in selection of casting process. General foundry principles and precautions. 136 pages. 21 tables. 29 illustrations.

ALCOA BUILDING, PITTSBURGH 19, PA.

PRODUCTS SOLD BY ALCOA

NOTE: This list of products contains a minimum number of cross-referenced items necessary for the readers convenience. Many products—cast, forged, draw pressed, extruded, impact extruded, screw machine and job shops—are produced to customers' specifications. Your nearest Alcoa sales office can be helpful in recommending the most efficient application of these products to your needs.

ACSR (aluminum cable steel reinforced)

Alclad aluminum
- Pipe
- Plate
- Sheet
- Tube
- Wire

Aluminas (see Chemicals)

Angles

Bar
- Hexagonal
- Rectangular
- Special shapes for screw machine stock

Barrels

Beams

Beer barrels

Billets or blooms for wrought aluminum products

Bolts

Brazing flux and wire

Bus (see Electrical conductors)

Cable (see Electrical conductors)

Carboys

Casting alloy ingot

Castings
- Die
- Permanent mold
- Plaster mold
- Sand
- Semipermanent mold

Channels

Chemicals
- Aluminas
  - Activated
  - Calcined
  - Hydrated
  - Low soda
  - Tabular

ALCOA PRODUCTS *(Continued)*

- Chemicals *(Concluded)*
  - Aluminum fluoride
  - Cryolite
  - Fluoboric acid
  - Gallium
  - Sodium acid fluoride
  - Sodium fluoride
- Circles, sheet and plate
- Closures, bottle
  - Sealing machines
- Coiled sheet
- Coiled tube
- Cold-headed products
- Collapsible tubes for packaging tooth paste, drugs, caulking compounds, greases, etc.
- Conduit, rigid
- Copings
- Corrugated sheet
- Cryolite insecticide
- Die castings
- Draw press products
- Drums, shipping
- Electrical conductors
  - Cable, all-aluminum or ACSR (aluminum cable steel reinforced)
  - Cable fittings and accessories
  - Buses
    - Channels
    - Flat
    - Tubular
  - Bus fittings and accessories
  - Fuse wire
  - Wire
- Electrical metallic tubing
- Extruded shapes
- Fasteners
  - Bolts
  - Nails
  - Nuts
  - Rivets
  - Screws
  - Screw machine products
  - Washers
- Finishes
  - Alumilite
  - Alrok
  - Electroplating
  - Other finishes are available
- Fluoboric acid
- Fluorides (see Chemicals)
- Foil
  - Condenser
  - Insulating
  - Household
  - Milkbottle hoods
  - Packaging
- Forgings, hammer and press
- Fuse wire
- Gallium
- Grained ingot
- Gravel stops
- H-beams
- Hammer forgings
- Handrail pipe and fittings
- I-beams
- Impact extrusion products
- Ingot
  - Casting alloy
  - For wrought products
  - Metallurgical granulated
- Insecticide, cryolite

Continued on next page

Irrigation pipe
Kettles
Lighting sheet
Lithograph sheet
Milkbottle hoods, foil
Moldings (see Extruded shapes)
Nails
Nuts
Paint pigment, aluminum
Patterned sheet
Permanent mold castings
Piano plates
Pig
Pigments
- Powder and paste for paint and printing ink

Pipe (see also Tube)
- Construction
- Handrail, and fittings
- Irrigation
- Standard, and fittings

Pistons
Plate (see Sheet)
- Alclad
- Circles
- Odd-shaped blanks with sheared or sawed edges
- Rectangular
- Tapered
- Tread

Plaster mold castings
Powder, aluminum (see also Pigments)
- Dusting
- Rubber compounding

Press forgings
Process equipment (made to specification)
Rectangular tube
Rectangular wire, rod and bar
Reflector sheet
Rivets and rivet wire
Rod
- Redraw
- Round

Roofing sheet
Sand castings
Screening wire
Screws
- Machine
- Sheet metal
- Special types
- Wood

Screw machine products (made to specification)
Screw machine stock (see also Rod, Bar)
Seals (bottle closures) and sealing machines
Semipermanent mold castings
Sheet (see also Plate)
- Alclad
- Circles
- Coiled
- Flat
- Odd-shaped blanks with sheared or sawed edges
- Specialty sheet
  - Alumilite
  - Brazing
  - Corrugated

ALCOA PRODUCTS *(Concluded)*

Sheet *(Concluded)*
- Specialty sheet
  - Lithograph
  - Patterned
  - Recording circles
  - Reflector
  - Roofing
  - Siding
- Tapered

Shipping containers
- Beer barrels
- Carboys
- Drums

Siding sheet

Sodium acid fluoride

Sodium fluoride

Solder and flux

Spandrels

Square tube

Structural assemblies (made to specification)

Structural shapes (rolled and extruded)

Tanks, welded

Tees

Thin-wall containers

Thread lubricant and compound

Thresholds

Tool and jig plates

Tooth paste tubes

Tread plate

Tube (see also Pipe)
- Alclad
- Coiled
- Electrical metallic
- Heat exchanger
- Round
- Square
- Special shapes

Tubes, collapsible

Welding materials
- Flux
- Wire

Washers

Wheels, truck, trailer and bus
- Disc
- Spoke

Window sills

Wire
- Alclad
- Flattened
- Hexagonal
- Rectangular
- Round
- Rivet
- Special shapes
- Square
- Welding

Wire, electrical (see Electrical conductors)

Zees

COMMERCIAL FORMS OF MAGNESIUM PRODUCTS sold by Alcoa include Castings, Forgings, Sheet and Plate, Extrusions, Tube and Pipe, Rod and Bar, and Structural Shapes. Also available are Pipe Line and Water Tank Anodes.

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